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March 1966

d) Publications:

M. Lipeles, R. Novick, and N. Tolk, "Direct Detection of Two-Photon Emission from the Metastable State of Singly Ionized Helium," Phys. Rev. Letters 15, 690 (1965).

B. Budick, S. Marcus, and R. Novick, "Level-Crossing Spectroscopy with an Electric Field; Stark Shift of the 3^2P Term in Lithium," Phys. Rev. 140, A1041 (1965).

M. Lipeles, R. Novick, and N. Tolk, "Optical Excitation with Very Low Energy Ions," Phys. Rev. Letters 15, 815 (1965).

e) Papers Presented at Scientific Meetings:

American Physical Society Meeting, New York, June 23-25, 1965.

E. B. Saloman and W. Happer, Jr., "Coherence Narrowing and Collision Broadening in the $(6p7s)^3P_1{}^o - (6p^2)^3P_{0,1,2}$ Transitions in Lead," Bull. Am. Phys. Soc. 10, 596 (1965).

A. Khadjavi, A. Lurio, and W. Happer, Jr., "Electric-Field Level Crossings in Mercury," Bull. Am. Phys. Soc. 10 596 (1965).

American Physical Society Meeting, Chicago, Illinois, October 28-30, 1965

R. C. Isler, S. Marcus, and R. Novick, "Fine and Hyperfine Structure of the 4P State of Li^7," Bull. Am. Phys. Soc. 10, 1096 (1965).

W. Happer, Jr., A. Khadjavi, and A. Lurio, "Electric-Field Hanle Effect in Mercury and Cadmium," Bull. Am. Phys. Soc. 10, 1096 (1965).

M. Lipeles, R. Novick, and N. Tolk, "Radiation from the Impact of Very Low Energy He^{+}," Fourth International Conference on Physics of Electronic and Atomic Collisions, L'Université Laval, Quebec, Canada, August 2-6, 1965.

P. Feldman, M. Levitt, S. Manson, R. Novick, and G. Sprott, "Zeeman Quenching of the $(1s2s2p)^4P_{5/2}$ Metastable State in Lithium," Zeeman Centennial Conference, Zeeman Laboratorium der Universiteit van Amsterdam, Amsterdam, Netherlands, September 6-11, 1965.

Joint Services Technical Advisory Committee Meeting, November 22, 1965.

W. Happer, Jr., "Two Relaxation Times for Excited Atoms."

M. Levitt, "Zeeman Quenching of Metastable Autoionizing States in the Alkalis."

M. Lipeles, "Direct Detection of Two-Photon Emission from the Metastable State of Singly Ionized Helium."

N. Tolk, "Optical Excitation with Very Low Energy Ions."

f) Reports:

Columbia Radiation Laboratory Quarterly Progress Report No. 11, 16 June 1965 - 15 September 1965, pp. 3-33; ibid. No. 12, 16 September 1965 - 15 December 1965, pp. 3-26.

g) Description of Research:

I. DIRECT DETECTION OF THE TWO-PHOTON DECAY MODE

Two-photon decay of the metastable $2^2S_{1/2}$ state of singly ionized helium has been directly detected by coincidence-counting techniques. This is believed to be the first conclusive evidence for the existence of such transitions in hydrogen-like atomic systems. The present experiment detected the decay in flight of a slow (12-eV) beam of metastable helium ions. Ionized helium was chosen in preference to hydrogen because the two-photon lifetime and the Stark quenching rate are each smaller by a factor of 64 in the helium. In addition, standard ion-beam techniques could be employed to focus and control the beam.

The apparatus consists of an electron-bombardment ion source, differential pumping chambers for pressure reduction, and a detection chamber with two phototubes, one of which is movable about the beam axis. Individual photon events are processed by means of fast-coincidence circuits. The first differential vacuum separation chamber contains a microwave cavity through which the beam passes. This cavity may be excited at 14 kMc/sec (the Lamb-shift frequency for He^+) to quench the metastable ions.

A plot of the single-photon counting rate as a function of the electron bombarding energy shows the expected threshold at 65 eV for the formation of the 2S state of He^+.(1) A curve of the dependence of the single-photon counting rate on the power used to excite the microwave-quenching cavity

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1. CRL Quarterly Progress Report, September 15, 1965, p. 3.

shows the exponential dependence on rf power that is expected for the quenching of metastable ions. The residual singles count at low-power levels arises from charged particles and gas excitation. Counts from the two phototubes that are in time coincidence are observed when the electron bombarding energy is greater than 65 eV and in the absence of rf quenching power. This counting rate agrees with the observed singles rate and the estimated two-photon decay rate. A curve showing the dependence of the coincidence rate on the electron bombarding energy has the same threshold and shape as the singles excitation curve. The dependence of the coincidence rate on rf quenching power is similar to that of the single-photon counting rate except that there is no residual signal at full rf power. This indicates that all of the coincidence counts arise from metastable ions.

The coincidence count observed at various angular positions of the movable phototube is in good agreement with the curve which is obtained by integrating the theoretical angular factor $(1 + \cos^2\theta)$ over the area of the phototube cathodes and over the length of the beam exposed to the detector. Further work is in progress to measure the spectral distribution of the photons.

II. DIRECT LIFETIME MEASUREMENTS

Work has been resumed to obtain a one percent measurement of the lifetime of the metastable helium ion. An essential part of this program was the construction of an ion drift tube which has now been assembled and leak tested. Assembly of the detector apparatus is now in progress.

III. METASTABLE AUTOIONIZING ATOMS

A. Metastable Alkali Atoms

A magnetic resonance rf spectrometer is being constructed to study the hyperfine structure of the metastable states in potassium, rubidium, and lithium. In this apparatus, the metastable beam passes through three separate magnetic fields in succession and then into a specially designed detector. The magnetic field in the first region is large ($\approx$ 15 kG) and serves to quench all but two long-lived (unmixed) states. In the second region, which has a low dc field, an applied radio-frequency field induces Zeeman transitions from one of the long-lived states into shorter-lived ones. The final magnetic-field region is identical with the first and quenches the shorter-lived states populated in the intermediate-field region. Thus, when the proper resonance frequency is applied in the second magnetic field, a decrease in the metastable-beam intensity is observed in the detector.

The determination of this resonance frequency as a function of the dc magnetic-field strength in the transition region will allow calculation of the g_F value and thus lead to identification of the J value of the long-lived states. In addition, the long lifetimes of these states (typically 10^{-4} sec) imply that narrow transition linewidths ($w \approx 10$ kc) will be obtained. Calculation of the hyperfine structure on the basis of the resonance data should then permit the determination of the nuclear electric quadrupole moment and possibly the magnetic octupole moment to far greater accuracy than would be possible with other techniques.

B. Studies of the He^- Ion

The development of the instrumentation and equipment necessary for producing and studying the He^- ion is proceeding. The existing Cockcroft-Walton accelerator has been modified to accelerate negative ions, and measurements are now under way to determine the intensity and dispersion of the He^- beam.

The large (20-kG) magnet of the old Columbia University cyclotron has become available for this work, and measurements of field strength and uniformity under the new configuration will be initiated in the near future. The electronic equipment necessary to operate the magnet is under construction, and designs for the vacuum chamber, deflecting system, and detecting units are now being prepared.

IV. ELECTRIC-FIELD HANLE EFFECT

Work was continued on the use of level-crossing signals associated with the electric-field Hanle effect to make precise measurements of differential Stark shifts in excited atomic states. With these techniques, measurements have been made of the differential Stark shift in the $^3P_1$ states of mercury and cadmium. For mercury the value has been determined to be 2360 ± 70 cps/(kV/cm)^2, while for cadmium the value is 2515 ± 75 cps/(kV/cm)^2.

The basic experimental arrangement for the measurements on cadmium was identical to that for mercury.(3) Electric field strengths up to 50 kV/cm were used, and the quadratic electric-field dependence of the differential Stark shift was confirmed to within experimental error.

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3. CRL Quarterly Progress Report, March 15, 1965, p. 5.

The present program has been extended to include a study of the electric-field level-crossing effects in the alkali metals. To do this a cesium Stark cell was prepared. It was soon evident, however, that the cell walls became conductive and could not support a potential difference. Efforts are still in progress to produce a suitable scattering cell for the alkalis.

V. FINE STRUCTURE OF SINGLY IONIZED LITHIUM

Experimental work on the measurement of the Zeeman hyperfine structure of the 2^3P state of singly ionized lithium by a resonance method was continued.

The interference produced by spurious signals generated by the rf power has been eliminated. However, a careful search for an rf-induced magnetic dipole transition between a set of two magnetic sublevels has so far been unfruitful.

VI. HYPERFINE STRUCTURE OF GROUP IIA ISOTOPES

Significant improvements were made in the preparation of barium cells for observation of Hanle-effect and double-resonance signals. A molybdenum cell was loaded with natural barium which had been distilled into a molybdenum plug, and the entire filling process was carried out in the vacuum system used to bake out cells. This procedure greatly reduced the possibility of an oxide layer forming on the barium.

The $6^1P_1 - 6^1S_0$ Hanle effect was detected when the cell prepared in this way was heated to 380°C. This signal was maximum at approximately 500°C. The high-field level crossing was seen at 500°C with signal-to-noise ratio of about 30 with a time constant of 30 seconds. Tests on this cell will continue.

VII. FINE AND HYPERFINE STRUCTURE OF THE 3P STATE OF Li^7

Measurements[4] which are accurate to a few parts in 10^6 have been obtained for the magnetic fields at which the four $\Delta m = 2$ level crossings occur in the 3P state of Li^7.

Theoretical calculations[5] of the spacings between successive hyperfine crossings have been completed which relate the magnetic-dipole and electric-quadrupole coupling constants to the measured values of the crossing fields. The quadrupole moment of Li^7 thereby computed differs in both sign and magnitude from a published value measured by electric-resonance techniques in LiH molecules. Attempts will be made to resolve this apparent discrepancy between level-crossing and electric-resonance techniques.

VIII. LOW-ENERGY ION IMPACT PHENOMENA

Incident to the study of two-photon decay of the 2S state of He^+, observation was made of radiation due to the impact of very slow helium ions on the rare gases and on some molecular gases. The dependence of the cross section for this process on the kinetic energy of the He^+ beam shows unexpected features down to the lowest energies studied (5 eV). For example, there is a sharp peak at 10 eV for the production of uv photons in Xe. The absolute cross sections are typically of the order of 10^{-16} cm^2 and in some cases are almost an order of magnitude larger. In at least one case the radiation has been shown to result from charge exchange with simultaneous excitation.

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4. CRL Quarterly Progress Report, September 15, 1965, p. 24.

5. CRL Quarterly Progress Report, December 15, 1965, p. 15.

Previous studies of optical excitation by ion impact have been performed at much higher energies and have not revealed the structure at the lower energies. Energy-balance considerations show that the reactions studied here involve the transfer of a large fraction of the kinetic energy into internal electronic energy. The excitation clearly involves nonadiabatic nonradiative transitions between the levels of the molecular-ion complex formed during the collision. The low-energy peaks in the cross section imply that the molecular-energy levels are shifted in energy during the collision until they nearly cross. Aside from their intrinsic interest, these results may have important bearing on plasma, laser, and atmospheric phenomena.

IX. RELAXATION OF OPTICALLY ORIENTED ATOMS

Under many experimental conditions, the decay of an ensemble of excited atoms is characterized by several relaxation times. Physically, these are the lifetime of the population of excited atoms, the lifetime of the average magnetic dipole moment (or orientation), the lifetime of the average electric quadrupole moment (or alignment), and the lifetimes of higher atomic multipole moments. Each multipole moment of the excited atoms decays with a characteristic lifetime because of the isotropy of the surrounding medium. In the limit of low vapor pressure, all of these lifetimes reduce to the natural radiative lifetime of the atom. In level-crossing experiments one can measure the lifetime of orientation and alignment separately. This is in contrast to classical nuclear-magnetic-resonance experiments, where only one parameter can be measured. The added flexibility in level-crossing experiments arises from the possibility of measuring the polarization of the fluorescent light.

The existence of two lifetimes has been observed in Hanle-effect signals from the first $^3P_1{}^o$ state in lead when the signal was subject to resonant self-broadening, and also in the presence of foreign gas broadening and coherence narrowing. A precise measurement of the resonant self-broadening of the $(6s^26p7s)^3P_1{}^o$ state of lead has determined the collision-induced reaction rate to be $3.2(1) \times 10^{-8}$ $cm^3/sec \times N$, where N is the lead atomic density, for densities up to 6×10^{15} atoms/cm^3, and confirms that the broadening is primarily due to a resonance process. This value is in excellent agreement with the theoretical relaxation rate of $3.0(2) \times 10^{-8} \times N$. The lifetime of the $(6s^26p7s)^1P_1{}^o$ state in lead has been determined from preliminary results to be $5.08(30) \times 10^{-9}$ sec.